HANSON

Thermal Conductivity of Concrete

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THERMAL CONDUCTIVITY OF CONCRETE

BY

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This is to certify that the thesis of CLAUDE LEROY HANSON entitled THERMAL CONDUCTIVITY OF CONCRETE was prepared under my personal supervision; and I recommend that it be approved as meeting this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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THERMAL CONDUCTIVITY OF CONCRETE.

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INTRODUCTION.

A number of tests have been made by various investigators to determine the heat properties of concrete. The tests performed to find the thermal conductivity of concrete have been few and the results have not been concordant. The only published data on this property of concrete are in articles by Professor C. L. Norton and Mr. Ira H. Woolson. Mr. L. A. Waterbury and Mr. A. W. Wheeler made some tests along this line at the University of Illinois, and the results of their tests are printed in their theses.

In the experiments performed by Prof. Norton thin pieces of concrete were molded around a plate of iron heated by a current of electricity. The outsides of the specimens were covered with a brass plate kept at a constant temperature by running water over it. The energy supplied to the plate gave the quantity of heat entering the plate. The temperatures of the plates and concrete were measured with thermal couples. These experiments showed that the flow of heat was directly proportional to the area, to the difference of temperature, to the time, and inversely proportional to the thickness of the concrete.

Experiments on cubes and prisms of concrete were performed by Mr. Woolson. The specimens were placed in the door of a gas furnace which was kept at a constant temperature. Thermal couples were used to determine the changes of temperature for various definite distances from the heated side. In the article in the

"Proceedings of the American Society of Testing Materials," Volume VII, written by Mr. Woolson, no numerical constants are given, but the conclusion reached was that "two or three inches of properly mixed concrete would resist a fierce conflagration for hours without serious rise on the other side."

In the tests made by Mr. Waterbury and Mr. Wheeler, cylinders and prisms of concrete were used, and thermometers were placed in them at definite distances from the surfaces exposed to the heat. Only the change of temperature caused by the variation in the temperature of the air was used by Mr. Waterbury, while Mr. Wheeler heated his specimens with electric lamps. The specimens were packed in a good non-conductor of heat.

The general method used in the tests described in this thesis was the same as that used by Mr. Wheeler. Different sized specimens and a different mixture of concrete, however, were used.

DESCRIPTION OF TESTS.

The tests were made on a 1:2:4 mixture of broken limestone concrete. The mixture was such that water came to the surface only after vigorous tamping. The specimens were stored for 30 days in damp sand and then stored in a dry place for 30 days in order that they might become thoroughly dried.

The general method of making the tests consisted in heating the surface of a specimen and reading temperatures from thermometers placed at various distances from this heated surface. The thermometers were incased in asbestos to prevent loss of heat from the holes. Two specimens of different form were used, one a

rectangular prism and the other a short cylinder. In testing the prism the heat was applied at one end, while in the cylinder the heat was applied at the side. By the use of the differently shaped specimens, two somewhat different formulas for computing the thermal conductivity were obtained. In order to be able to get the temperatures near the centers of the specimens, holes were made by placing 3/8-inch rods in them while they were being molded. These rods were pulled out after the concrete had set.

The first test for thermal conductivity was made on a solid concrete prism 70 days old, one foot square in cross section and eighteen inches long. The sides of the specimen were packed in mineral wool two inches thick to reduce radiation as much as possible. The heat was applied to one end by electric lamps arranged as shown in Figure I. Thermometers were placed in the mineral wool along the sides of the specimen about 1 1/2" from the concrete, and no appreciable rise in temperature was shown. Thermometers placed in the wool on the top of the specimen during the first test showed a small rise in temperature and the top was covered with boards for the remaining tests. Thermometers were placed at 2-inch intervals along the axis of the specimen and at 4-inch intervals in a line one inch from the side. The results of this test are shown in Tables I and VIII.

The second, third, and fourth tests were made on the same specimen, and the results of these tests are shown in Tables II and IX, III and X, and IV and XI, respectively. The second test was made when the specimen was 77 days old, the third when 81 days old, and the fourth when 84 days old.

The fifth and sixth tests were made on a solid concrete cylinder 22 inches high and 16 inches in diameter. This cylinder was packed in mineral wool except for the sides, where the heat was applied by means of electric lamps. The arrangement of the thermometers and lamps is shown in Figure I. The results of these tests are shown in Tables V and XII, and VI and XIII, respectively. The fifth test was made on the specimen when 91 days old, and the last test when 98 days old.

From the temperatures read and the corresponding distances from the heated surface, curves were plotted with the temperatures as ordinates, and the distances as abscissae. From these curves were obtained the temperature gradient, - the rate of change of temperature for the section under consideration. If two sections are dx distance apart and the difference in temperature is dt, then the temperature gradient is $\frac{dt}{dx}$, or the tangent of the angle that the tangent to the curve at that point makes with the axis of the abscissae.

By making $dt = t_1 - t_2$ and $dx = d$, a short length of the prism, the average value of the temperature gradient in the length d can be determined from

$$\text{Tan } B = \frac{t1 - t2}{d}.$$

If Q = the quantity of heat passing the section under consideration,

A = area of the section,

t_1 = temperature on the hot side,

t_2 = temperature on the cool side,

d = distance between two sections considered,

T = time during which Q units of heat pass the section A,

then $$Q = \frac{K(t1 - t2)TA}{d},$$

or $$K = \frac{Q}{AT \tan B} \qquad (1)$$

where K = a constant depending on the thermal conductivity of the concrete, - the quantity of heat transmitted through the concrete when d, (t_1 - t2), A, and T are each unity.

The temperature-distance curves were plotted so that one vertical division = one degree, and one horizontal division = one centimeter. From these curves the values of the temperature gradients were scaled directly for the points under consideration, and the quantities of heat passing the different sections were obtained by multiplying the area to the right of the section and between adjacent curves by the specific heat of the concrete. The areas between curves were obtained by the use of a polar planimeter.

In the computation for the cylinder tests, the heat added to concentric rings of concrete was calculated. Temperature-distance curves were drawn the same as for the beam, and the temperature gradients were scaled from these. Using the concentric rings gave the following formula for the quantity of heat, q, added to each concentric ring:

$$q = \pi (r_1^2 - r_2^2)(t_1 - t_2)s,$$

where r_1 and r_2 are the distances of the cylindrical surfaces of the ring from the center,

$t_1 - t_2$ = the average rise in temperature of the ring in the time T,

s = specific heat of the concrete.

To find the total quantity of heat passing a section, consider the cylinder divided into n concentric rings of unit height, then $Q = \pi s\left[(r_1^2-r_2^2)(t_1-t_2) + (r_2^2-r_3^2)(t_2-t_3) +\text{---}\ r^2{}_n(t_n-t'_n)\right]$, in which

Q = total quantity of heat passing the section,

t'_n= Initial temperature of the concrete at the center at the beginning of the time T.

Also $Q = K\ T\ A \tan B.$

where A = area of face of ring on the outside.

Equating and solving for (K),

$$K = \pi s \frac{(r_1^2-r_2^2)(t_1-t_2) + (r_2^2-r_3^2)(t_2-t_3) +\text{--}\ r_n^2(t_n-t'_n)}{A\ T \tan B} \quad (2)$$

In finding the quantity of heat flowing through a substance, the specific heat of that substance must be known. The specific heat is the quantity of heat necessary to raise one gram of the substance one degree at a given temperature.

In finding the specific heat the calorimeter method was used. If

W = weight of water in the calorimeter,

M = weight of concrete,

t_1= initial temperature of the concrete,

t_2= " " " " water,

t_3 = final " " " " and concrete,

s = specific heat of the concrete,

then $$s = \frac{W(t_3-t_2)}{M(t_1-t_3)} \quad (3)$$

In making the specific heat tests, the concrete was broken into pieces 2 inches in the largest diameter, and these pieces

placed in an electrically heated box. They were left in this box for over two hours, until the temperature became constant. From here the concrete was quickly transferred to the calorimeter, a glass jar carefully packed in mineral wool. In computing the specific heat of the concrete, the amount of heat taken to raise the glass to the final temperature was considered. The results of these tests are shown in Table VII.

RESULTS

In a set of experiments of this nature there are always some errors which cannot be wholly eliminated. Some of the errors in these tests were compensating; for example, the errors in reading the thermometers and in drawing the corresponding temperature-distance curves would cause a corresponding error in the computed quantity of heat; but any error in one curve would only make the area included between it and one adjacent curve larger than it should be, while the area between it and the other adjacent curve would be correspondingly smaller, and since the average values of the thermal conductivity were taken, the errors would be compensating. There was some error in not having the heat applied evenly all over the surface, and to loss by radiation from the sides. The temperature readings taken along the sides of the specimen showed that these errors could not have been considerable, since they showed practically the same temperatures as the center thermometers did at the same distances from the heated surface. In reading the thermometers it was necessary to remove them partially from the specimen, but no appreciable drop in temperature was noted

until after five seconds had elapsed. All readings were made in less time than this.

The greatest error entering into the computation was the error in determining the values of the temperature gradient. Since these values were scaled from the temperature-distance curves, any error in these curves would cause variations in the temperature gradients that were not wholly compensating. Another source of slight error was the loss of heat through the mineral wool packing on the top of the specimen. This wool was not packed as much as was the wool along the sides, and consequently more heat was carried to the boards and air. By placing thermometers in the wool on top and in the sides it was found that the wool on top rose in temperature a considerable amount, even after the boards were placed on top, while that on the sides rose very little. From the probable error of the mean it can be seen that the results are reliable to within three percent of the mean.

Plate 10 shows the relation between the time and the rise in temperature for certain distances from the heated end.

Although there is a comparatively large variation in the individual values for the thermal conductivity, most of the results are close to the mean of all the values. The plotted results show that the thermal conductivity of concrete is a constant for the temperatures used in this set of experiments.

FIGURE I

ARRANGEMENT OF THERMOMETERS AND LAMPS

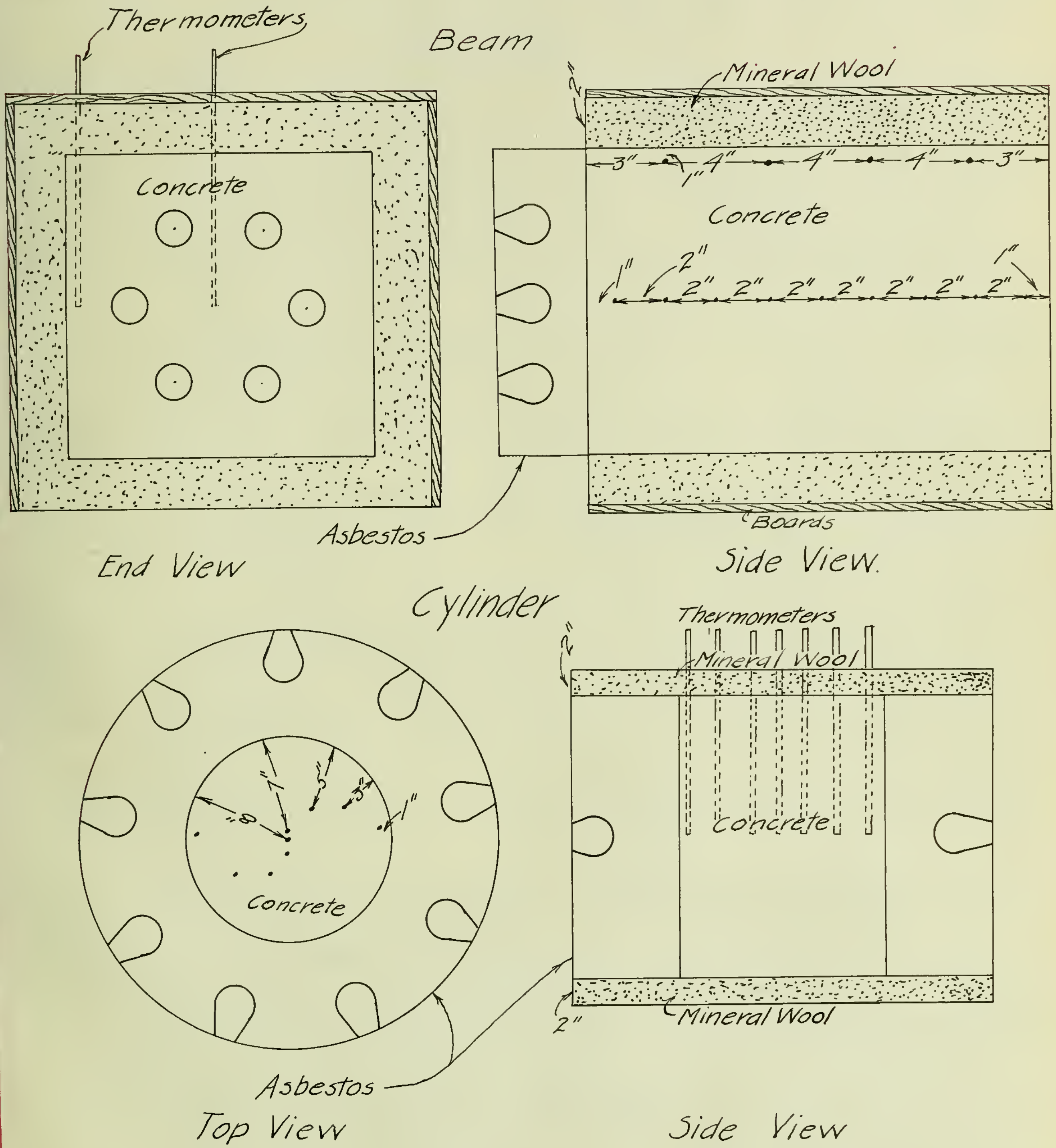


TABLE I
TEMPERATURES and CORRESPONDING DISTANCES FROM HEATED SURFACE

Concrete Beam-Test No.1.

Dist., cm.	0	2.5	7.6	12.7	17.8	22.9	28.0	33.0	38.1	43.2
Time	Temperatures - C°									
8:30	28.0	28.0	28.0	28.0	28.5	29.0	29.0	29.0	28.2	28.0
9:00	59.0	32.0	29.0	28.0	28.5	29.0	29.0	29.0	28.2	28.0
9:30	67.2	35.7	30.5	29.0	28.5	29.0	29.0	29.0	28.2	28.0
10:00	65.0	38.5	32.8	30.0	29.0	29.0	29.0	29.0	28.2	28.0
10:30	66.0	39.5	34.0	31.0	29.8	29.0	29.0	29.0	28.2	28.0
11:00	69.0	41.2	36.0	32.5	30.5	29.5	29.0	29.0	28.2	27.5
11:30	72.0	43.6	37.0	33.2	31.0	30.0	29.0	29.0	28.2	27.5
11:55	73.5	44.6	38.0	34.0	32.0	30.3	29.0	29.0	28.2	27.5
12:50	77.0	48.0	40.5	36.0	33.0	31.0	29.8	29.0	28.2	27.5
1:30	75.0	48.5	42.0	37.5	34.0	32.0	30.0	29.3	28.2	27.5
2:00	76.0	49.8	43.0	38.4	35.0	32.8	30.5	29.8	28.4	28.0
2:30	77.0	51.0	44.0	39.2	35.6	33.0	31.0	30.0	28.6	28.0
3:00	77.5	51.8	45.0	40.0	36.0	33.5	31.2	30.0	28.8	28.5
4:00	77.5	53.0	46.2	41.2	37.2	34.6	32.0	30.8	29.2	29.0
4:35	76.5	53.5	47.0	42.0	38.0	35.0	32.5	31.0	29.2	29.0

TABLE II

TEMPERATURES and CORRESPONDING DISTANCES FROM HEATED SURFACE

Concrete Beam-Test No. 2

Dist, cm.	0	2.5	7.6	12.7	17.8	22.9	28.0	33.0	38.1	43.2
Time	Temperatures - C°									
8:30	24.0	22.8	22.8	22.8	23.0	22.8	22.8	23.0	23.0	23.5
9:00	63.0	27.8	23.6	22.8	23.0	22.8	22.8	23.0	23.0	23.5
9:30	65.5	32.0	26.4	24.0	23.0	22.8	22.8	23.0	23.0	23.5
10:00	66.8	34.8	28.2	25.0	23.7	23.0	22.8	23.0	23.0	23.6
10:30	65.5	37.0	30.0	26.4	24.3	23.7	23.0	23.1	23.2	23.7
11:00	70.5	39.0	32.0	28.0	25.5	24.0	23.0	23.1	23.3	23.7
11:25	71.0	40.8	33.6	29.0	26.3	24.7	23.8	23.8	23.3	23.7
11:50	72.0	42.0	34.9	30.0	27.0	25.0	24.0	24.0	23.7	24.0
12:30	71.0	43.1	36.4	31.8	28.2	26.0	24.5	24.2	23.8	24.2
1:00	73.0	44.6	37.5	33.0	29.0	26.8	25.0	24.8	24.2	24.2
1:30	74.0	46.0	39.0	34.0	30.0	27.2	25.8	25.0	24.6	24.6
2:00	73.0	46.8	39.5	35.0	31.0	28.0	26.0	25.5	24.8	24.8
3:00	74.0	49.0	42.0	37.0	32.5	29.4	27.3	26.2	25.3	25.2
4:00	75.0	50.8	43.2	38.0	34.0	30.6	28.4	27.1	26.2	26.0
5:00	76.0	52.0	45.0	40.0	35.0	32.0	29.3	28.0	26.8	26.6

TABLE III
TEMPERATURES and CORRESPONDING DISTANCES FROM HEATED SURFACE

Concrete Beam - Test No. 3

Dist., cm.	0	2.5	7.6	12.7	17.8	22.9	28.0	33.0	38.1	43.2
Time	Temperatures - C°									
8:30	26.2	24.0	23.6	23.6	24.0	24.0	24.0	24.0	24.3	24.4
9.55	68.0	35.0	28.0	25.2	24.0	24.0	24.0	24.0	24.3	24.4
11:00	70.0	40.0	32.8	28.5	26.0	25.0	24.0	24.0	24.3	24.4
11:55	72.0	43.0	35.2	30.8	27.5	26.0	25.0	24.2	24.3	24.4
12:55	72.0	45.2	38.0	33.0	29.2	27.1	25.8	24.9	24.6	24.4
2:00	72.0	47.0	40.0	35.0	31.0	28.1	26.5	25.5	25.0	24.4
3:00	72.0	48.3	41.3	36.5	32.5	29.6	27.2	26.0	25.5	24.6
4:00	71.5	50.0	43.0	38.0	33.8	30.9	28.0	26.5	26.0	24.8
4:50	73.0	50.3	43.7	39.0	34.5	31.5	28.8	27.2	26.0	25.0

TABLE IV
TEMPERATURES and CORRESPONDING DISTANCES FROM HEATED SURFACE

Concrete Beam - Test No. 4

Dist, cm.	0	2.5	7.6	12.7	17.8	22.9	28.0	33.0	38.1	43.2
Time	Temperatures - C°									
8:30	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
9:00	61.0	28.8	25.2	25.0	25.0	25.0	25.0	25.0	25.0	25.0
9:30	65.5	33.2	27.7	25.8	25.0	25.0	25.0	25.0	25.0	25.0
10:00	67.6	36.0	29.4	26.7	25.5	25.0	25.0	25.0	25.0	25.0
10:30	69.0	38.8	32.0	28.0	26.2	25.6	25.0	25.0	25.0	25.0
11:00	69.8	40.5	33.3	29.2	27.0	26.0	25.5	25.0	25.0	25.0
11:30	71.8	42.5	35.2	30.8	28.0	26.6	25.8	25.0	25.0	25.0
11:55	73.0	43.5	36.2	31.6	28.6	26.8	26.0	25.5	25.0	25.0
1:00	72.5	46.0	39.2	34.5	30.8	28.2	26.6	26.0	25.0	25.0
1:30	70.0	47.0	40.2	35.0	31.3	28.8	27.0	26.0	25.0	25.0
2:00	73.0	48.0	41.2	36.0	32.0	29.6	27.6	26.2	25.2	25.0
2:30	73.0	48.8	42.0	36.7	32.6	30.0	27.8	26.5	25.2	25.0
3:25	73.0	50.5	43.2	38.0	34.0	30.8	28.5	27.0	26.0	25.2
4:30	73.0	51.8	45.2	39.8	35.2	31.8	29.2	27.8	26.6	25.6

TABLE V
TEMPERATURES and CORRESPONDING DISTANCES FROM HEATED SURFACE

Concrete Cylinder - Test No. 5

Dist, cm.	0	2.2	7.6	12.7	17.1	20.3	16.5	12.7	7.6	2.2
Time	A			Temperatures - C°						B
8:30	29.0	28.4	29.0	28.4	28.6	28.0	28.0	29.0	28.5	28.4
9:00	73.0	33.6	30.0	29.0	29.0	28.0	29.0	29.0	29.8	34.0
9:30	83.0	39.0	32.5	29.8	29.0	28.2	29.2	29.8	32.4	38.4
10:00	75.0	32.5	35.8	31.8	30.4	30.2	31.0	32.0	35.4	41.0
11:00	78.0	48.5	41.5	36.8	34.6	34.6	35.5	36.8	41.0	46.5
12:00	85.0	53.5	46.0	41.4	39.4	39.4	40.0	41.4	45.0	51.5
1.05	89.0	58.0	51.0	47.2	44.6	44.4	45.0	46.4	50.5	56.0
2:00	89.0	61.5	55.0	50.8	47.2	47.0	48.2	50.0	54.0	59.2
3:00	90.0	64.5	58.2	54.6	52.5	52.5	53.2	54.2	57.5	62.0
4:00	90.0	66.2	61.5	58.0	56.0	56.0	57.0	58.0	60.2	64.0

TABLE VI

TEMPERATURES and CORRESPONDING DISTANCES FROM HEATED SURFACE

Concrete Cylinder - Test No. 6

Dist., cm.	0	2.2	7.6	12.7	17.1	20.3	16.5	12.7	7.6	2.2
Time	A				Temperatures - C°					B
8:30	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0
9:00	76.0	32.2	26.0	23.1	23.0	23.0	23.0	23.0	25.8	32.0
9:30	83.0	37.0	28.5	25.0	24.0	24.0	24.2	25.1	28.2	36.7
10:00	79.0	40.5	32.0	27.3	24.5	24.4	24.9	27.4	31.6	40.0
11:00	79.0	46.3	38.0	32.1	28.8	29.0	29.2	31.8	37.7	46.0
12:00	78.0	51.5	42.6	36.9	33.4	33.4	33.8	36.5	42.5	51.0
1:00	85.0	56.2	47.9	43.0	40.2	40.2	40.5	42.5	47.7	55.6
2:00	89.0	59.3	52.5	47.3	46.5	46.4	46.8	47.0	52.4	59.0
3:00	91.0	62.0	56.0	52.0	50.5	50.0	51.0	51.6	55.5	61.4
4:00	90.0	66.0	61.0	57.2	55.0	55.0	55.2	57.0	60.5	65.5

TABLE VII

DATA and RESULTS OF SPECIFIC HEAT TESTS

Test No.	Weight of Water Grams	Weight of Concrete. Grams	Temperatures in C° Initial of Water	Initial of Concrete	Final of Mixture	Specific Heat in Calories.
1	124.4	51.9	26.8	63.5	30.0	0.291
2	116.2	39.1	26.5	64.0	29.0	0.277
3	115.2	45.4	26.0	64.0	29.0	0.279
4	124.6	35.0	26.5	64.0	28.8	0.292
5	127.7	44.5	26.1	65.0	29.0	0.289
6	118.8	36.5	26.0	65.0	28.2	0.252

Mean 0.281

TABLE VIII

VALUES OF THERMAL CONDUCTIVITY

Concrete Beam - Test No. 1

Ref. No.	Time	Distance From Heated Surface in Cm. 5 Tan. B	5 K	10 Tan. B	10 K	15 Tan. B	15 K	20 Tan B	20 K
1	4:35	1.35	0.0022	1.00	0.0027	0.85	0.0024	0.55	0.0023
2	4:00	1.35	0.0019	1.00	0.0020	0.85	0.0020	0.55	0.0019
3	3:00	1.35	0.0024	1.00	0.0028	0.85	0.0025	0.50	0.0030
4	2:30	1.35	0.0024	0.95	0.0027	0.70	0.0022	0.50	0.0019
5	2:00	1.35	0.0029	0.90	0.0034	0.70	0.0029	0.50	0.0032
6	1:30	1.25	0.0027	0.85	0.0032	0.75	0.0023	0.45	0.0021
7	12:50	1.35	0.0024	0.95	0.0022	0.60	0.0021	0.35	0.0022
8	11:55	1.30	0.0029	0.80	0.0031	0.50	0.0030	0.30	0.0025
9	11:30	1.00	0.0020	0.75	0.0020				
10	11:00	1.00	0.0033	0.70	0.0035				
11	10:30	1.00	0.0021	0.55	0.0028				
12	10.00	1.10	0.0024						
Mean			0.0024		0.0027		0.0024		0.0024
Probable Error			0.00008		0.00011		0.00010		0.00009

TABLE IX

VALUES OF THERMAL CONDUCTIVITY

Concrete Beam-Test No. 2

Ref. No.	Time	Distance From Heated Surface in Cm. 5 Tan.B	5 k	10 Tan.B	10 k	15 Tan.B	15 k	20 Tan.B	20 K
1	2:00	1.30	0.0026	0.90	0.0032	0.80	0.0025	0.50	0.0025
2	1:30	1.35	0.0034	1.00	.0033	0.80	0.0031	0.50	0.0030
3	1:00	1.35	0.0029	1.00	0.0025	0.75	0.0025	0.50	0.0024
4	12:30	1.30	0.0025	1.00	0.0025	0.70	0.0020	0.40	0.0021
5	11:50	1.30	0.0022	0.95	0.0022	0.60	0.0018	0.45	0.0024
6	11:25	1.35	0.031	0.90	0.0028	0.55	0.0027	0.30	0.0025
7	11:00	1.30	0.0028	0.90	0.0025	0.50	0.0021		
8	10:30	1.30	0.0028	0.70	0.0022	0.45	0.0020		
9	10:00	1.10	0.0024	0.55	0.0021				
10	9:30	1.10	0.0023						
11	9:00	0.70	0.0027						
Mean		0.0027		0.0026		0.0022		0.0025	
Pobable Error		0.00007		0.00010		0.00010		0.00007	

TABLE X
VALUES OF THERMAL CONDUCTIVITY
Concrete Beam Test No. 3

Ref. No.	Time	Distance From Heated Surface in Cm.							
		5		10		15		20	
		Tan. B	K	Tan. B	K	Tan. B	K	Tan. B	K
1	4:50	1.20	0.0020					0.65	0.0021
2	4:00	1.20	0.0025	1.10	0.0021	0.90	0.0019	0.60	0.0022
3	3:00	1.30	0.0020	0.90	0.0023	0.75	0.0022	0.60	0.0019
4	2:00	1.35	0.0024	1.00	0.0026	0.75	0.0027	0.55	0.0026
5	12:55	1.45	0.0023	1.00	0.0027	0.70	0.0027	0.45	0.0029
6	11:55	1.50	0.0023	1.00	0.0025	0.60	0.0027	0.30	0.0028
7	11:00	1.50	0.0025	0.85	0.0028	0.50	0.0028	0.20	0.0023
8	9:55	1.40	0.0023						
Mean		0.0023		0.0025		0.0025		0.0024	
Probable Error		0.00005		0.00007		0.00010		0.00008	

TABLE XI

VALUES OF THERMAL CONDUCTIVITY

Concrete Beam-Test No. 4

Ref. No.	Time	Distance From Heated Surface in Cm. 5 Tan.B.	5 K	10 Tan.B	10 K	15 Tan.B	15 K	20 Tan.B	20 K
1	4:30	1.35	0.0023	1.10	0.0025	0.90	0.0022	0.70	0.0021
2	3:25	1.40	0.0024	1.10	0.0025	0.90	0.0023	0.55	0.0028
3	2:30	1.25	0.0020	1.00	0.0020	0.80	0.0019	0.55	0.0023
4	2:00	1.30	0.0026	1.00	0.0027	0.80	0.0023	0.50	0.0022
5	1:30	1.40	0.0020	1.00	0.0020	0.75	0.0020	0.50	0.0018
6	1:00	1.35	0.0026	1.00	0.0028	0.65	0.0029	0.50	0.0020
7	11:55	1.20	0.0029	1.00	0.0025	0.65	0.0025	0.35	0.0028
8	11:30	1.35	0.0031	0.95	0.0032	0.65	0.0027	0.40	0.0022
9	11:00	1.30	0.0024	0.85	0.0026	0.50	0.0030	0.30	0.0021
10	10:30	1.20	0.0034	0.85	0.0030	0.40	0.0028	0.20	0.0025
11	10:00	1.30	0.0021	0.55	0.0022				
12	9:30	1.05	0.0024						
Mean		0.0025		0.0026		0.0025		0.0023	
Probable Error		0.00008		0.00005		0.00008		0.00007	

TABLE XII

VALUES OF THERMAL CONDUCTIVITY

Concrete Cylinder-Test No.5

Ref. No.	Time	Distance From Heated Surface in Cm. 5 TanB	5 K	10 TanB	10 K	10 TanB	10 K	5 TanB	5 K
1	4:00	0.95	0.0030	0.65	0.0028	0.70	0.0026	0.70	0.0029
2	3:00	1.05	0.0022	0.70	0.0021	0.55	0.0026	0.90	0.0022
3	2:00	1.10	0.0023	0.75	0.0020	0.75	0.0020	1.00	0.0024
4	1:00	1.20	0.0021	0.90	0.0030	0.75	0.0022	1.05	0.0018
5	12:00	1.25	0.0026	0.90	0.0026	0.75	0.0027	1.25	0.0020
6	11:00	1.25	0.0029	0.85	0.0034	0.70	0.0020	1.20	0.0020
7	10:00	1.10	0.0019	0.80	0.0018	0.80	0.0019	1.10	0.0023
8	9:30	1.00	0.0020	0.55	0.0024	0.65	0.0019	1.05	0.0022
Mean		0.0024		0.0025		0.0022		0.0022	
Prob. Error		0.00010		0.00012		0.00008		0.00009	

TABLE XIII

VALUES OF THERMAL CONDUCTIVITY

Concrete Cylinder-Test No. 6

Ref. No.	Time	Distance From Heated Surface in Cm.							
		5		10		10		5	
		TanB	K	TanB	K	TanB	K	TanB	K
1	4:00	0.95	0.0019	0.75	0.0020	0.70	0.0027	0.95	0.0034
2	3:00	1.10	0.0019	0.80	0.0023	0.70	0.0020	1.20	0.0021
3	2:00	1.30	0.0018	0.90	0.0020	0.85	0.0020	1.30	0.0027
4	1:00	1.50	0.0023	1.00	0.0019	1.00	0.0021	1.50	0.0020
5	12:00	1.65	0.0029	1.15	0.0027	1.20	0.0019	1.80	0.0024
6	11:00	1.70	0.0022	1.10	0.0025	0.90	0.0028	1.70	0.0021
7	10:00	1.50	0.0026	0.90	0.0020	0.80	0.0026	1.70	0.0019
8	9:30	1.55	0.0021	0.75	0.0021	0.70	0.0021	1.40	0.0019
Mean		0.0022		0.0023		0.0023		0.0023	
Prob. Error		0.00009		0.00009		0.00009		0.00012	

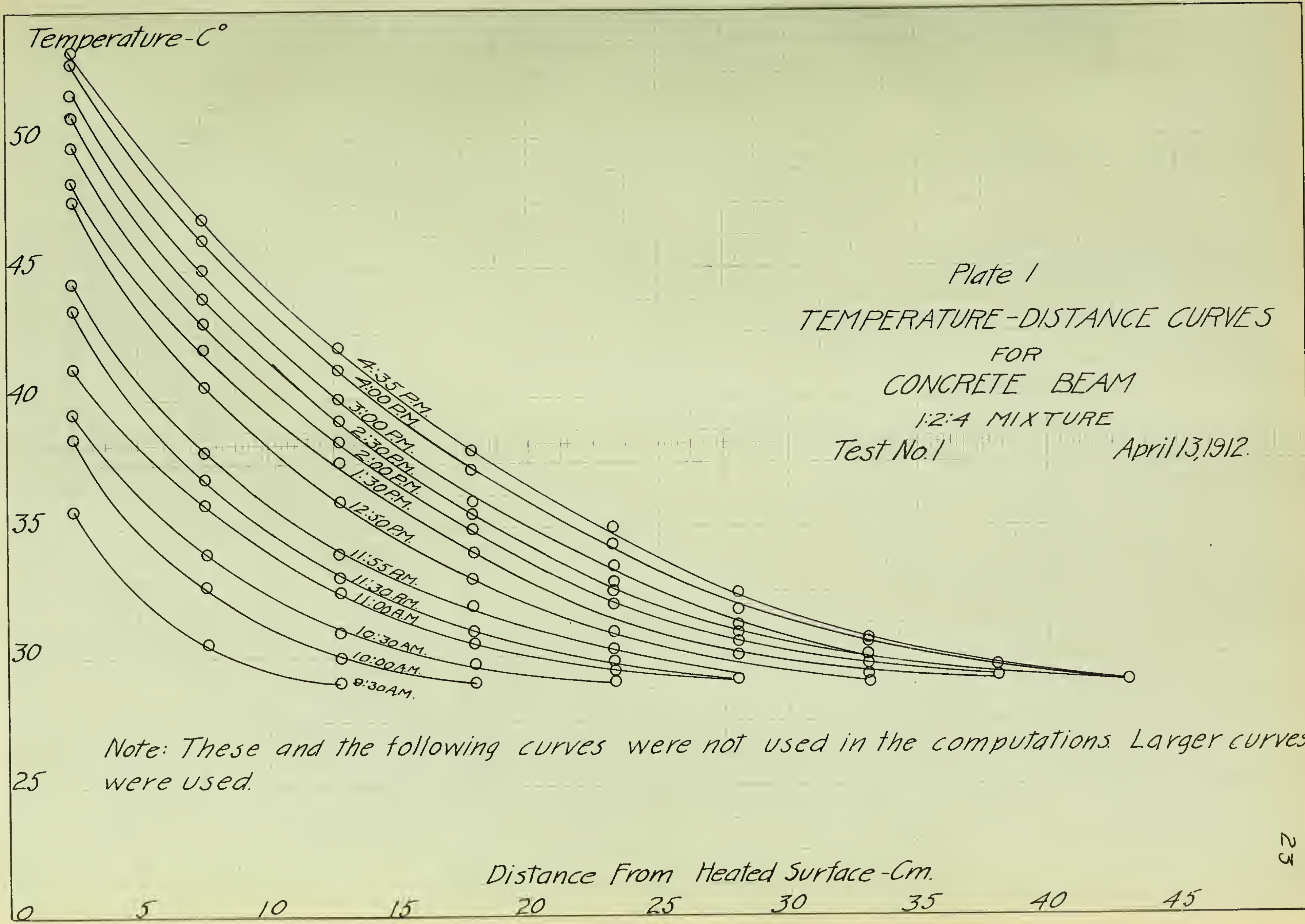


Plate I
TEMPERATURE-DISTANCE CURVES
FOR
CONCRETE BEAM
1:2:4 MIXTURE
Test No. 1
April 13, 1912.
Temperature-C°
50
45
40
35
30
25
4:35 P.M.
4:00 P.M.
3:00 P.M.
2:30 P.M.
2:00 P.M.
1:30 P.M.
12:50 P.M.
11:55 A.M.
11:30 A.M.
11:00 A.M.
10:30 A.M.
10:00 A.M.
9:30 A.M.
Note: These and the following curves were not used in the computations. Larger curves were used.
Distance From Heated Surface-Cm.
0
5
10
15
20
25
30
35
40
45

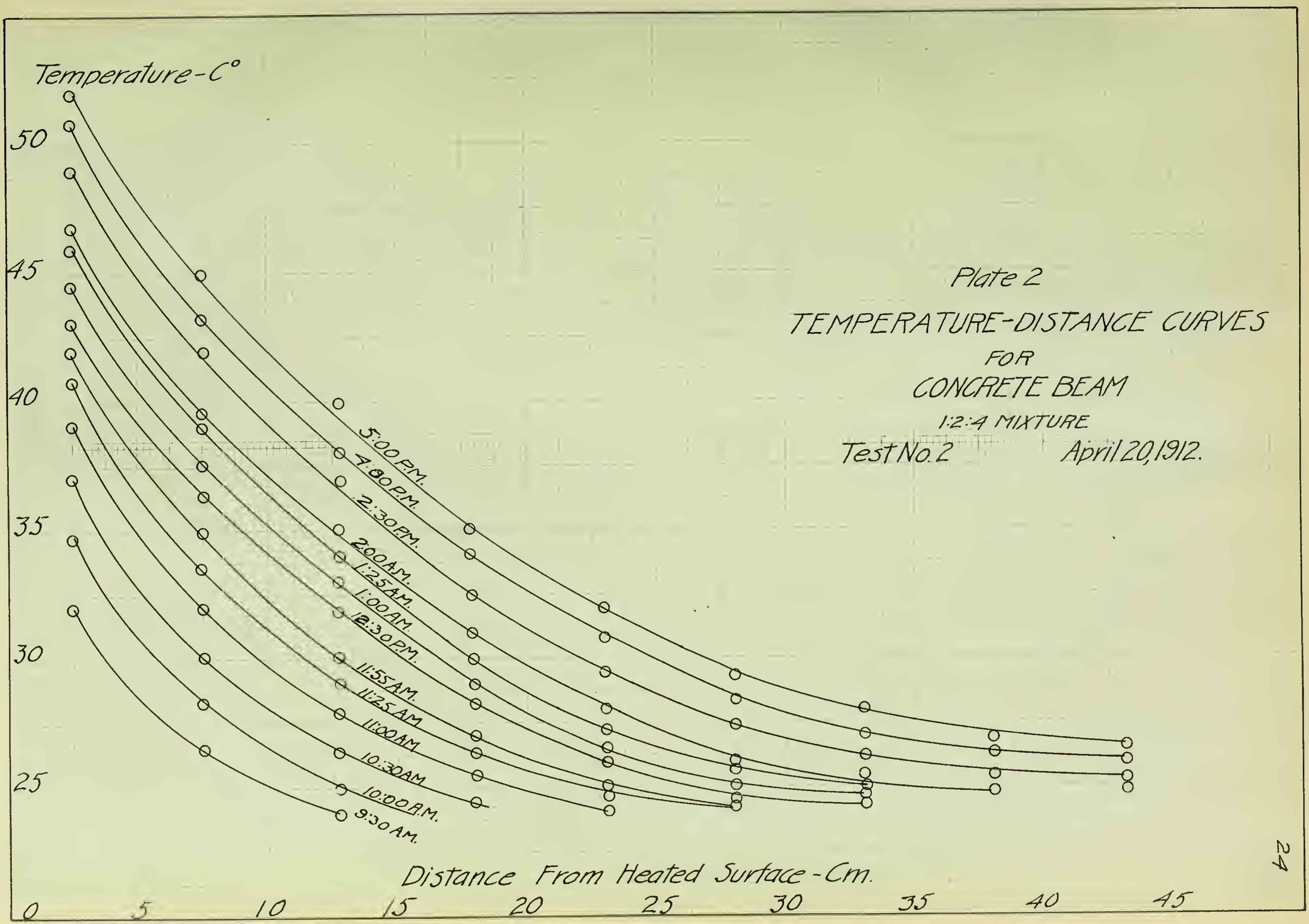
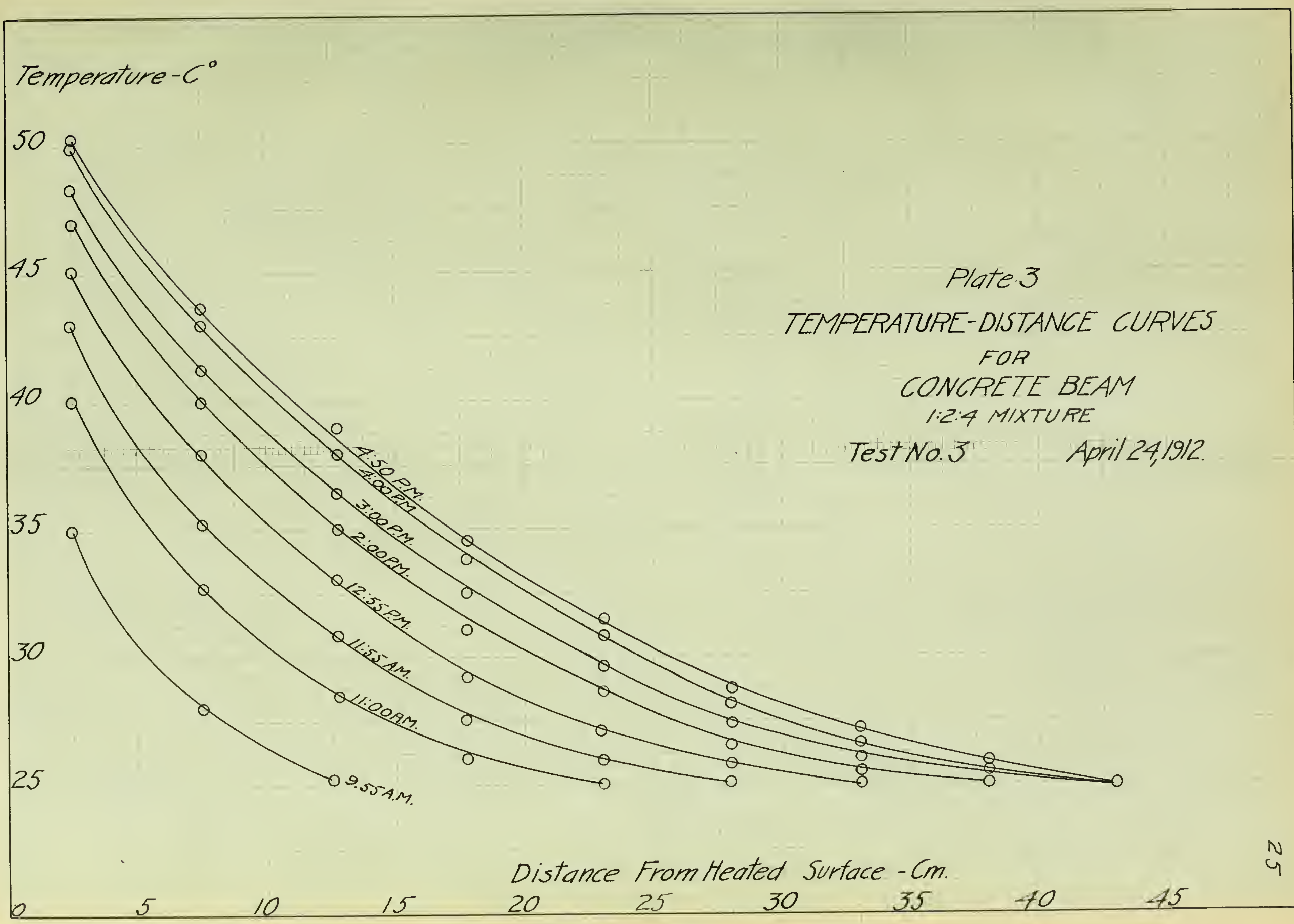


Plate 2
TEMPERATURE-DISTANCE CURVES
FOR
CONCRETE BEAM
1:2:4 MIXTURE
Test No. 2
April 20, 1912.
Temperature - C°
50
45
40
35
30
25
5:00 P.M.
4:00 P.M.
2:30 P.M.
2:00 AM.
1:25 AM.
1:00 AM.
12:30 P.M.
11:55 AM.
11:25 AM
11:00 AM
10:30 AM
10:00 A.M.
9:30 AM.
Distance From Heated Surface - Cm.
0
5
10
15
20
25
30
35
40
45


Temperature - C°
50
45
40
35
30
25
Plate 3
TEMPERATURE-DISTANCE CURVES
FOR
CONCRETE BEAM
1:2:4 MIXTURE
Test No. 3
April 24, 1912.
4:50 P.M.
4:00 P.M.
3:00 P.M.
2:00 P.M.
12:55 P.M.
11:55 A.M.
11:00 A.M.
9:55 A.M.
Distance From Heated Surface - Cm.
0
5
10
15
20
25
30
35
40
45

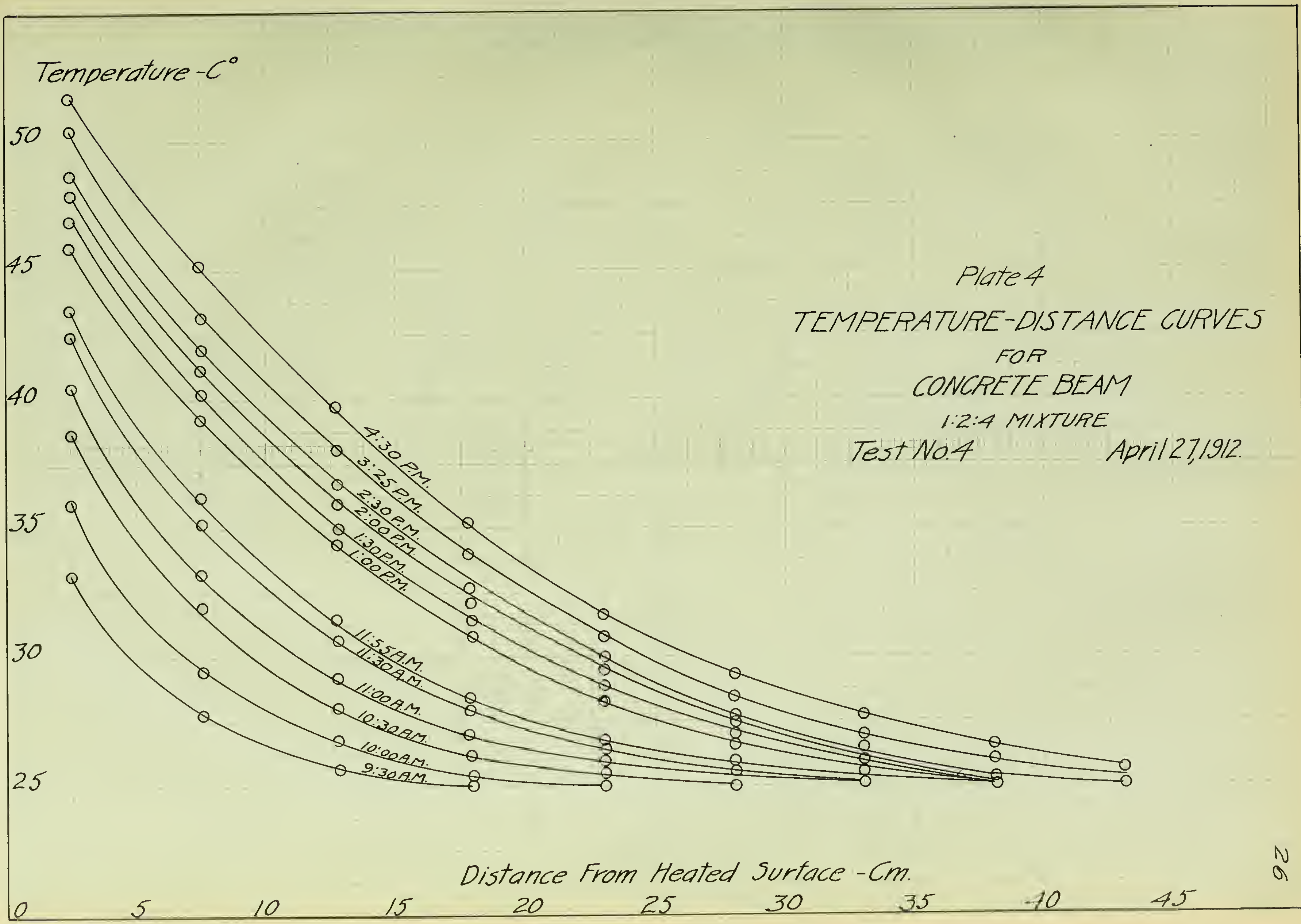


Plate 4
TEMPERATURE-DISTANCE CURVES
FOR
CONCRETE BEAM
1:2:4 MIXTURE
Test No. 4
April 27, 1912.
Temperature - C°
50
45
40
35
30
25
Distance From Heated Surface - Cm.
0
5
10
15
20
25
30
35
40
45
4:30 P.M.
3:25 P.M.
2:30 P.M.
2:00 P.M.
1:30 P.M.
1:00 P.M.
11:55 A.M.
11:30 A.M.
11:00 A.M.
10:30 A.M.
10:00 A.M.
9:30 A.M.

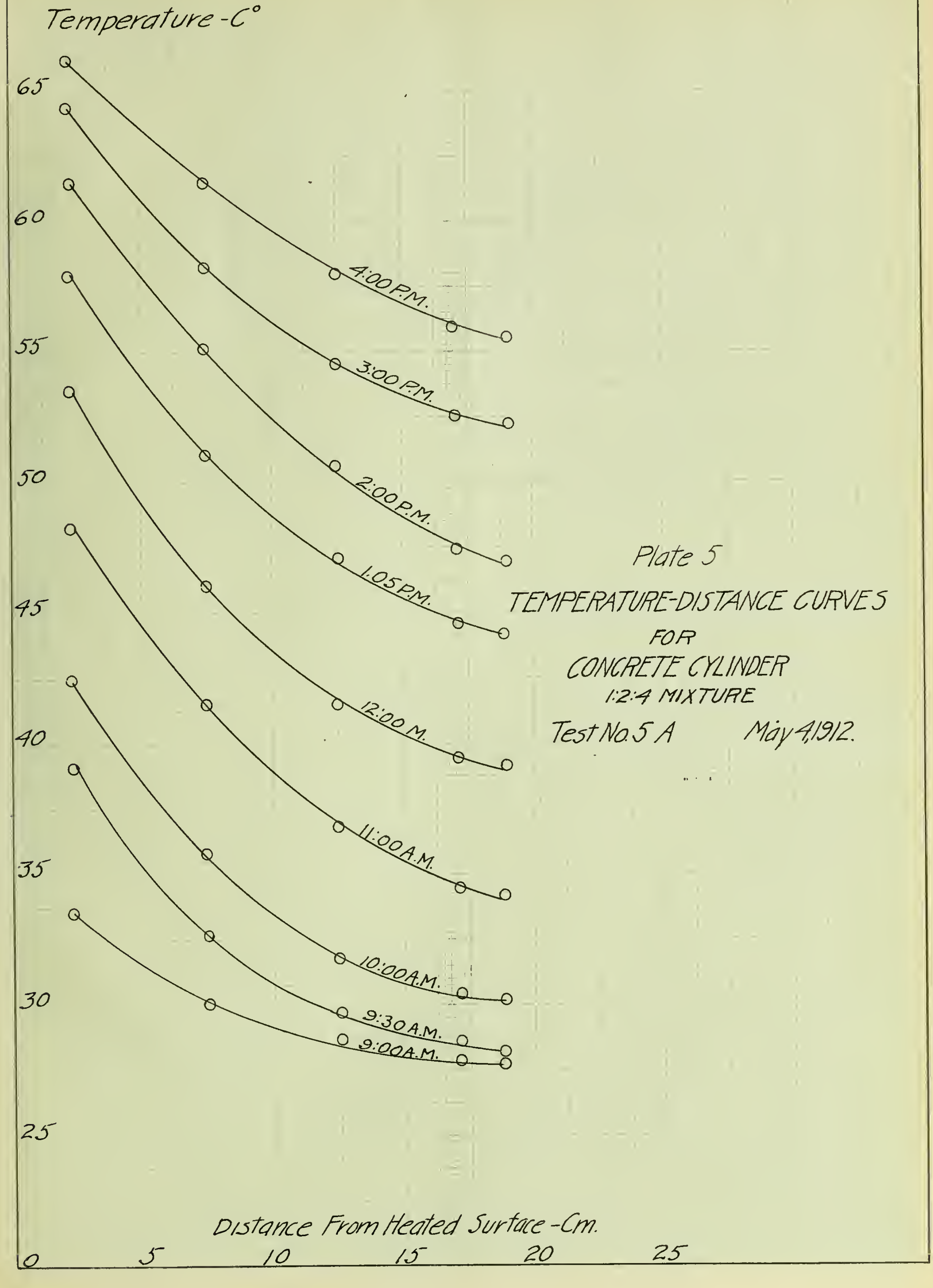


Plate 5

TEMPERATURE-DISTANCE CURVES
FOR
CONCRETE CYLINDER
1:2:4 MIXTURE

Test No. 5 A May 4, 1912.

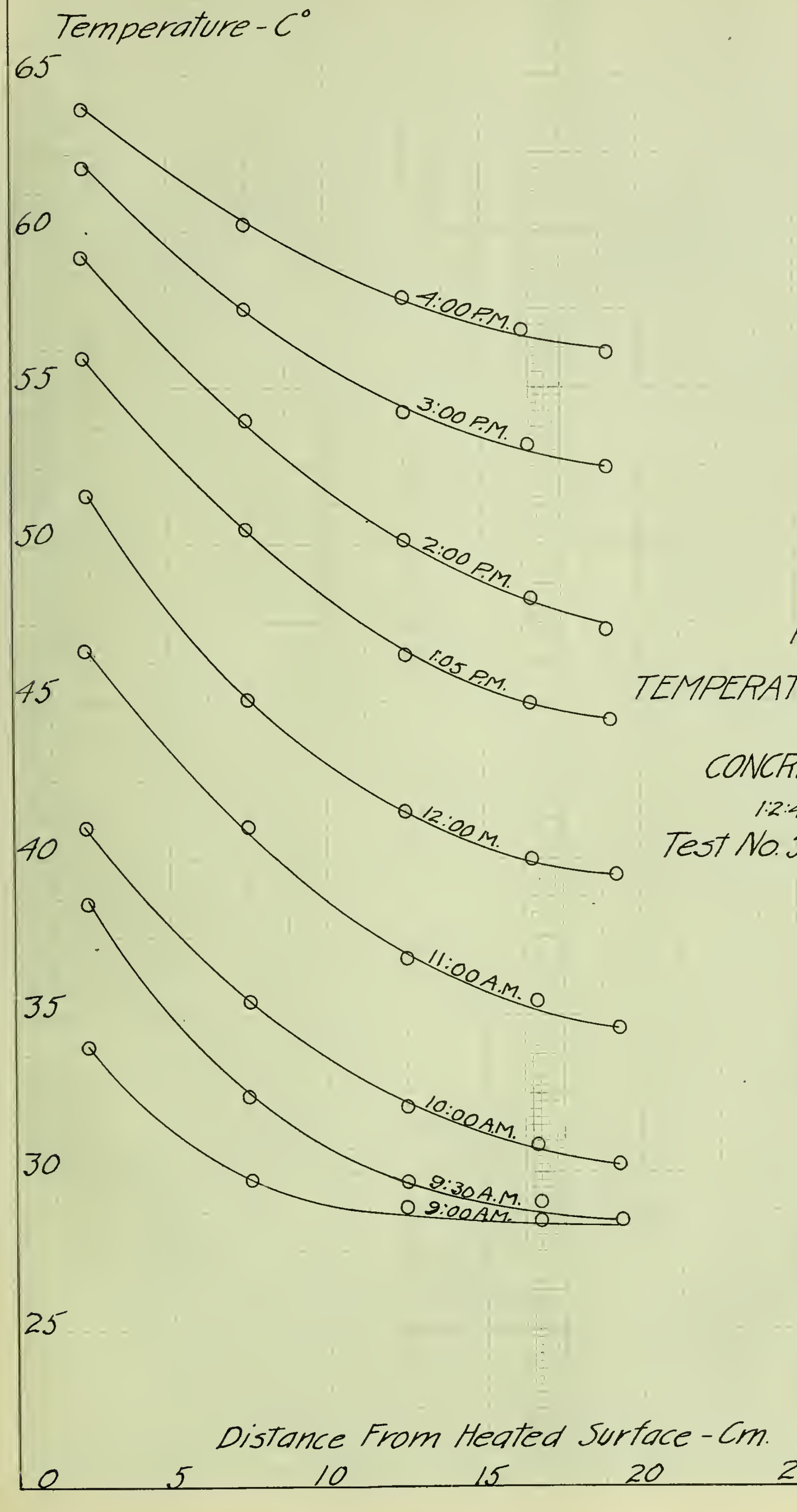


Plate 6

TEMPERATURE-DISTANCE CURVES

FOR

CONCRETE CYLINDER

1:2:4 MIXTURE

Test No. 5 B May 4, 1912.

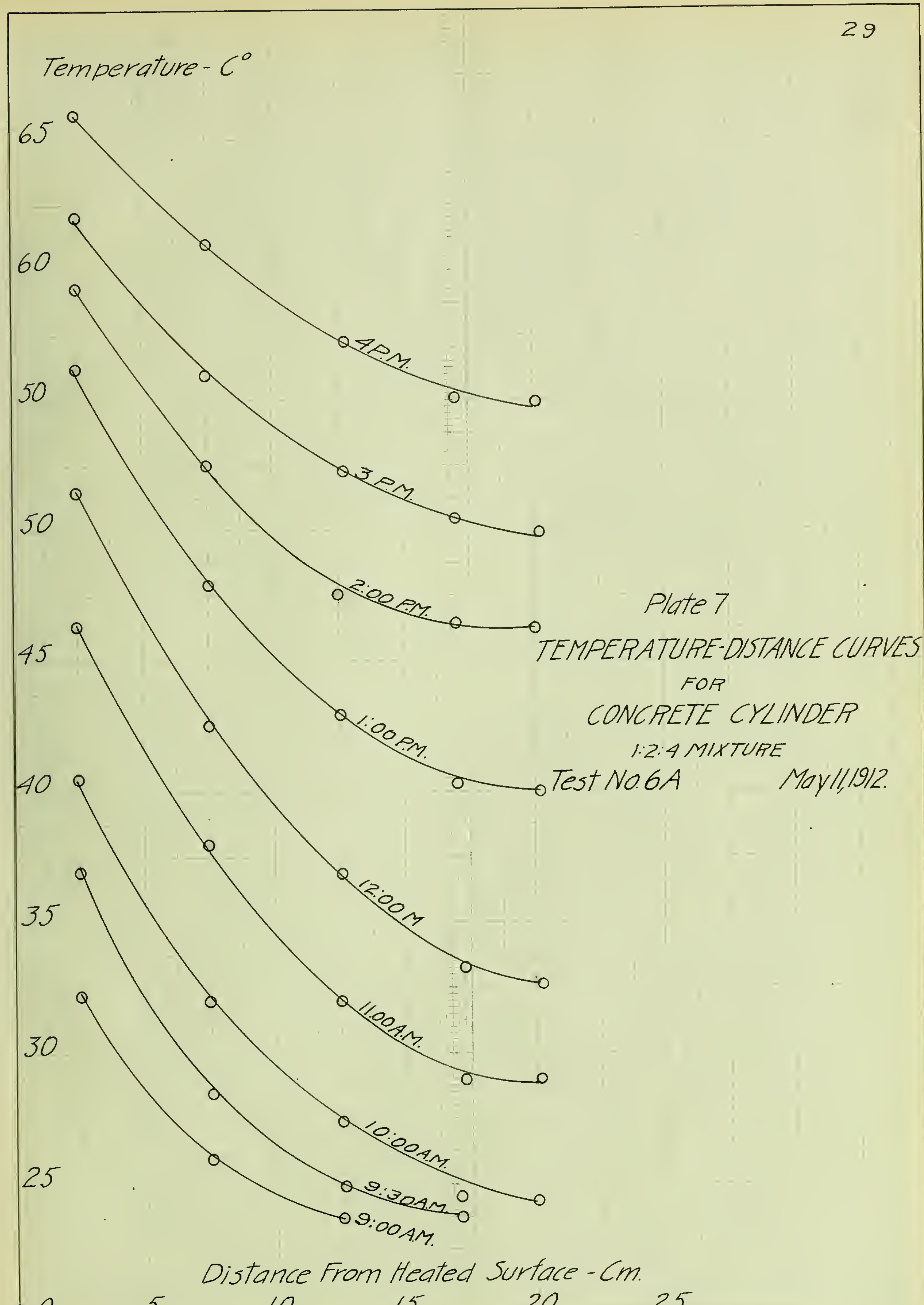


Plate 7
TEMPERATURE-DISTANCE CURVES
FOR
CONCRETE CYLINDER
1:2:4 MIXTURE
Test No. 6A May 11, 1912.

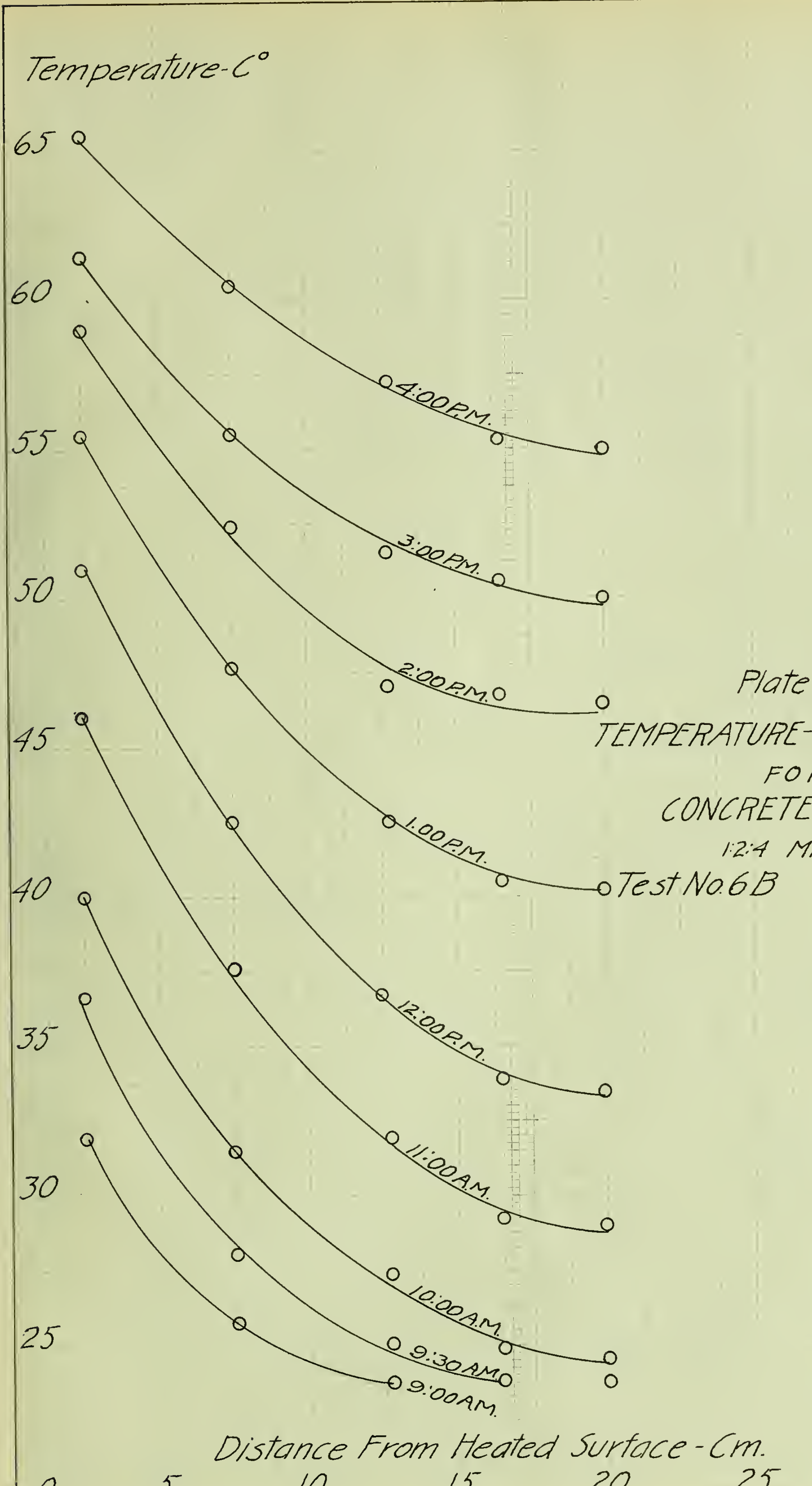
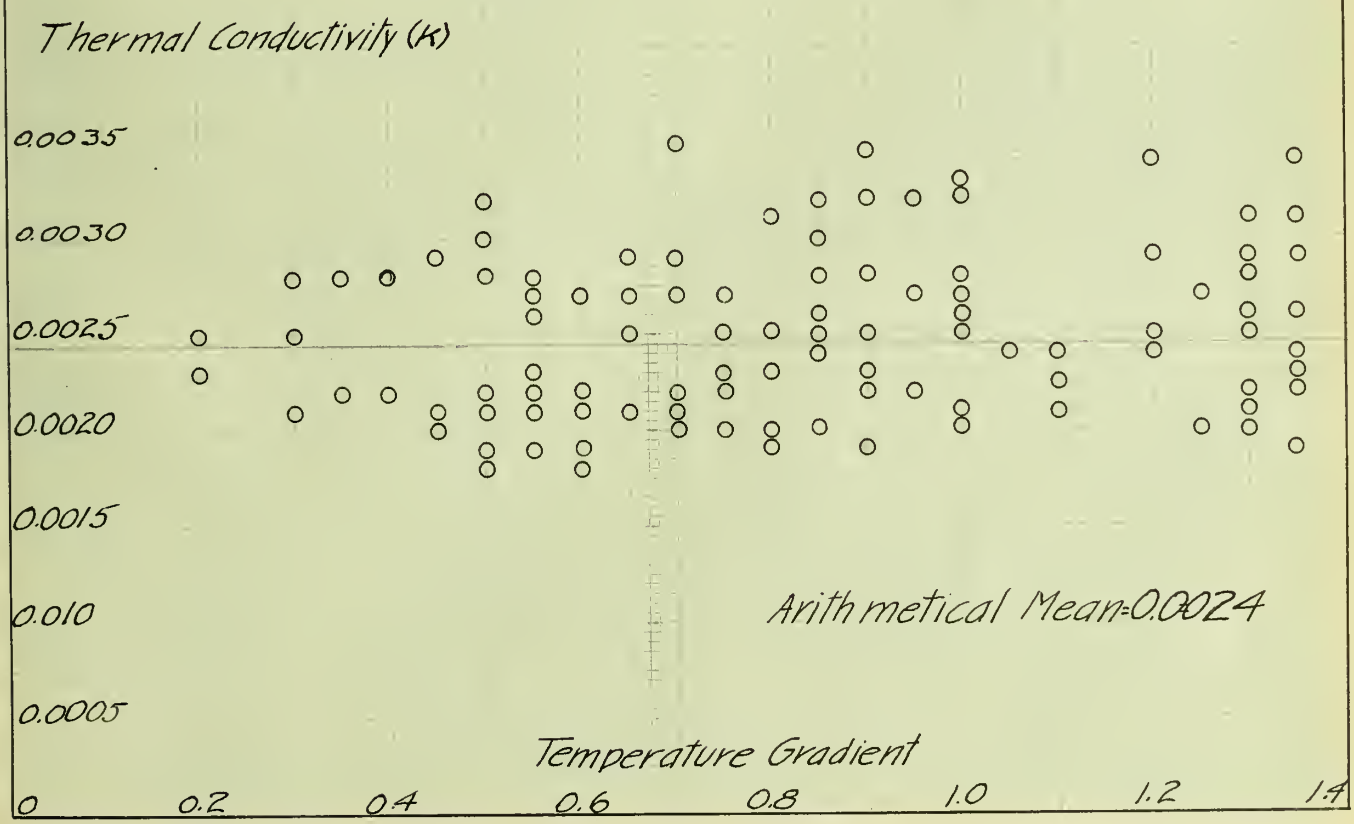


Plate 8
TEMPERATURE-DISTANCE CURVES
FOR
CONCRETE CYLINDER
1:2:4 MIXTURE
Test No. 6 B May 11, 1912.

Plate 9

CURVE SHOWING RELATION
BETWEEN
THERMAL CONDUCTIVITY
and
TEMPERATURE GRADIENT



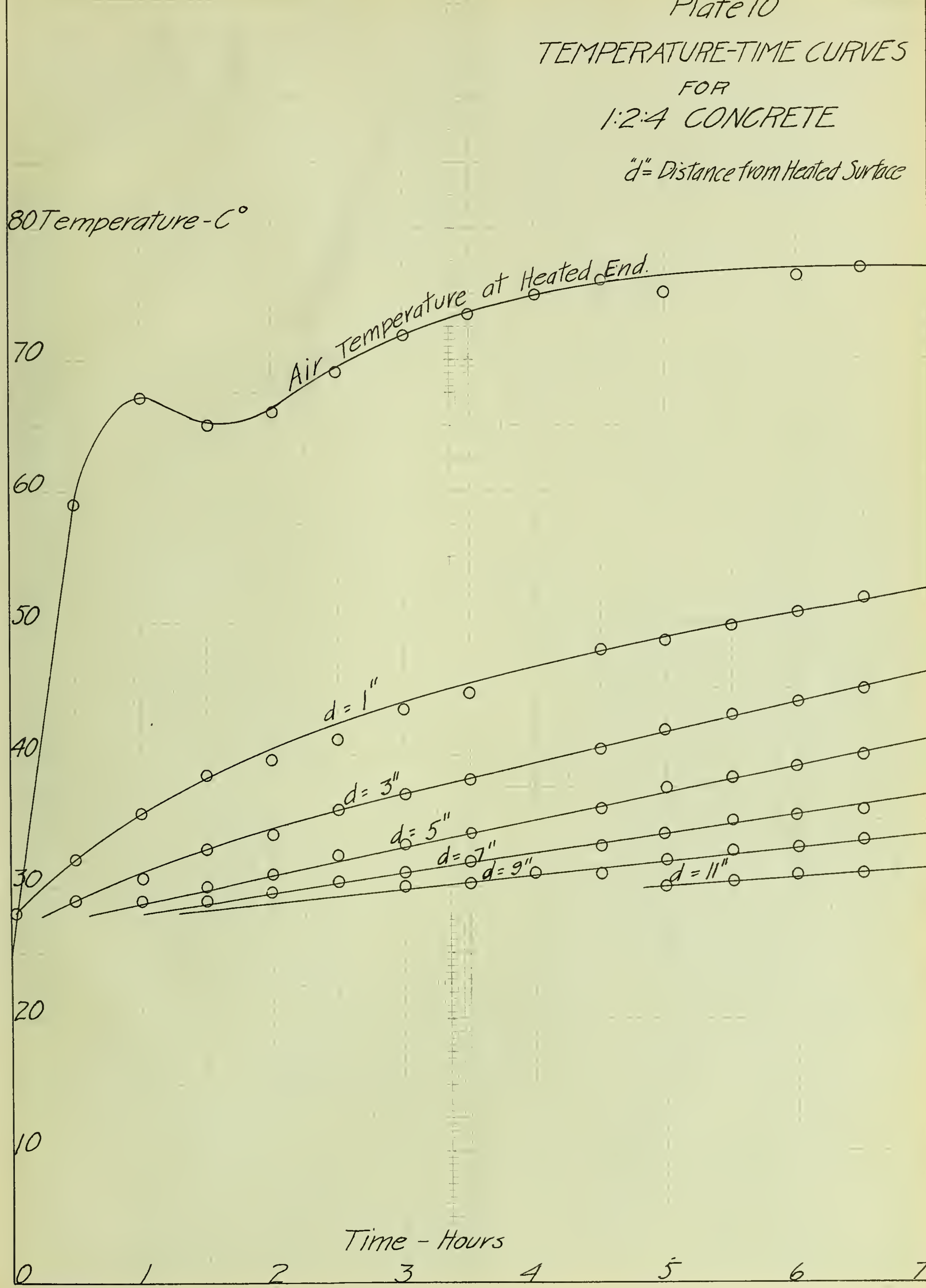


Plate 10
TEMPERATURE-TIME CURVES
FOR
1:2:4 CONCRETE
"d" = Distance from Heated Surface
80 Temperature - C°
70
60
50
40
30
20
10
Air Temperature at Heated End.
d = 1"
d = 3"
d = 5"
d = 7"
d = 9"
d = 11"
Time - Hours
0
1
2
3
4
5
6
7